Some Geotechnical Properties of Tokai Clay

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ABSTRACT: Series of subsurface investigation including in-situ and laboratory tests have been carefully planned and carried out for the design of embankments of Electrified Double Track over soft clay at Tokai, Kedah. Basically, settlement and stability are the 2 major issues for embankment constructed over soft clay. Therefore, it is prudent to have fundamental understanding on soft clay in order to prevent costly and time consuming remedial works. This paper describes the utilised approach in characterising and developing a fundamental understanding of the Tokai Clay, Kedah. Some important correlations have been established for key engineering properties such as compressibility and undrained shear strength parameters from good quality field and laboratory data. A correlation between physical soil properties with undrained shear strength from field vane shear test ($s_{u(fv)}$) and laboratory consolidation tests are established for practical usages in the geotechnical design. In addition, correlations involving the piezocone were also systematically derived from high quality field data.

KEYWORDS: Soft clay, undrained shear strength, empirical correlation, piezocone, field vane shear

1. INTRODUCTION

With the ever-growing economic activity in Malaysia, infrastructure development such as highway or railway interlinking the Southern and Northern region of Peninsular Malaysia, is deemed to be important in cultivating the industry. However, construction of such infrastructure would impose certain challenges to engineer especially when predicting the pre & post construction behavior of subsoil without established data.

During construction of the Electrified Double Track railway project across Northern region of Malaysia, which started in year 2007, a rather homogeneous subsoil layer consisting of 15m of soft clay was encountered at Tokai, Kedah. Soft clay is classified as clay with undrained shear strength less than 25kPa according to Brand & Brenner (1981) and the lack of understanding on the in-situ behavior of this thick layer of soft alluvium subsoil might result in unsafe and less optimum design.

A series of subsurface investigation consisting of in-situ and laboratory testing was planned and executed in details to study the geotechnical properties of the overburden soft clay at Tokai, Kedah. The soft clay is termed as Tokai Clay in this paper. Interpretation of engineering properties of Tokai Clay was carried out and correlations of vital properties such as undrained shear strength and compressibility parameters are established from both laboratory and in-situ testing for easy reference in the future for development at this area.

2. GEOLOGICAL FORMATION

The proposed Electrified Double Track is located at Peninsular Malaysia and stretches from Ipoh to Padang Besar with a total track length of 329 km. Figure 1 indicates the location of Tokai, the area of focus in this paper.

Tokai is underlain by the Alluvium formation as shown in Figure 2 and the age of Alluvium is Quarternary. Generally, Alluvium consists mainly of coastal plain marine deposits and the fluviatile deposits in main river valleys.

The subsoil of Tokai is relatively homogenous consisting of very soft to soft CLAY (15m thick) overlying dense silty SAND to SAND.

3. SUBSOIL PROPERTIES OF TOKAI CLAY

3.1 Basic Soil Properties

Figure 3 shows that the unit weight of Tokai Clay for top 12m is in the range of $12kN/m^3$ to $14kN/m^3$. This coincides with those unit weight encounters by past researchers for soft clay at Peninsular Malaysia as summarised by Saiful Azhar, 2004.

Figure 1 Location Plan of Tokai in Peninsular Malaysia (Image from www.googlemaps.com)

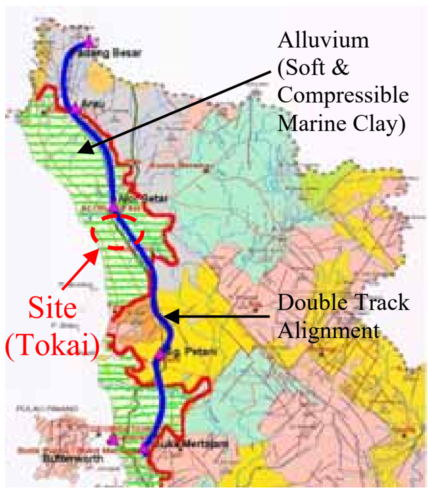

Figure 2 Geological Map at Site (Geological Map of Peninsular Malaysia, 8th Print, 1985 by Director General, Department of Mineral and Geoscience Malaysia)

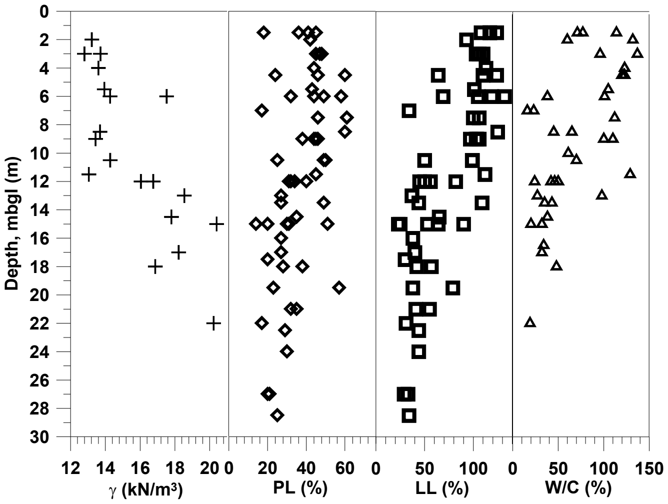

Figure 3 Basic Soil Properties at Tokai

Liquid Limits (LL) of Tokai Clay generally ranges from 50% to 150% and this is almost in agreement with those value suggested by Hussein (1995) for West Coast Peninsular's soft clay that ranges from 40% to 125%. Figure 3 indicates both the Plasticity Index and Liquid Limit of Tokai Clay decrease with increasing depth. The observed trend is in conjunction with conclusion drew by Hussein (1990) in his research on Peninsular Malaysia's soft clay that the Liquid Limit decreases with depth.

3.2 Compressibility

Generally, soft clay is located at low lying or flood prone area. Thus, filling is inevitable in order to achieve the required designed platform level to prevI:\Presentations & Publications\Technical Publications (G&P)\2016\19AGSSEA-2SEAGC\Tokai(LPT)ent flood. In view of low permeability of soft clay, controlling consolidation settlement is one of the main challenges once the subsoil is loaded by the fill.

Therefore, interpretations on compressibility parameters such as over-consolidation ratio (OCR), compression ratio (CR), recompression ratio (RR), coefficient of consolidation in vertical direction (c_v) are vital to facilitate settlement analyses. Some of the compressibility parameters of Tokai Clay such as OCR, CR, RR and c_v are presented in Figure 4.

It can be observed from Figure 4 that the CR of Tokai Clay is in the range of 0.3 to 0.6. Whilst, the RR ranges from 0.02 to 0.06. Besides, OCR of Tokai Clay decreases with increasing depth and ranges from 4.1 at the top and slowly decreases to 1.0 with depth.

The gradient of the linear part of the e – log σ' is the compression index, C_c and it is dimensionless. Often, C_c has been correlated to basic properties of subsoil to establish empirical correlations towards the understanding of subsoil behavior. Figure 5 exhibits the relationship between the C_c of Tokai Clay and its Liquid Limit. Whilst, the empirical equation Eq. (1) is as below:

$$C_c = 0.025LL - 1 \quad (1)$$

According to Leroueil et al (1983), the compression index, C_c of clay is influenced by the sensitivity of natural clays and generally it can be correlated to the void ratio and sensitivity of the subsoil. The relationship between C_c and natural void ratio is shown in Figure 6 and demonstrated by the below empirical equation Eq. (2):

$$C_c = 0.580e_o - 0.25 \quad (2)$$

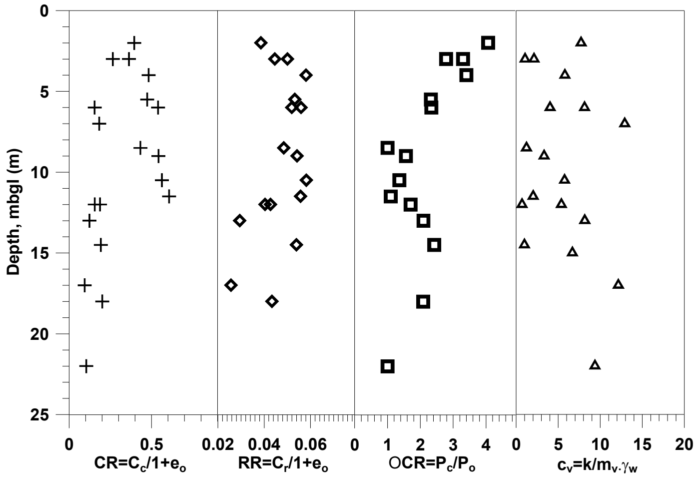

Figure 4 Compressibility Parameters for Tokai Soft Clay

In addition, attempts to correlates the water content with C_c has been done by Tan et al. (2003) for Klang Clay. The relationship between C_c with natural water content for Tokai Clay is presented by below empirical equation Eq. (3):

$$C_c = 0.015W_n - 0.80 \quad (3)$$

From the empirical correlations of C_c with LL, e_o and W_n respectively, it is observed that the obtained correlations are close to the those suggested by Tan et al. (2003) for Klang Clay. Besides, the correlations also similar to the linear correlation derived theoretically by Nishida (1956) for general undisturbed clay.

The recompression index, C_r and compression index, C_c are potent characteristic of soft clay. C_r is defined the same as C_c as elaborated in previous section except that it applies to the reloading portion of oedometer test. Figure 8 shows the ratio of C_c/C_r of Tokai Clay which ranges from 3.0 to 11.0.

4. UNDRAINED SHEAR STRENGTH

As mentioned earlier, the main problems in design of embankment over soft clay are settlement and stability. Stability of the embankment is most critical when the embankment height is the highest during construction (short term), after that the subsoil will gain in strength with time when the excess pore pressure dissipates.

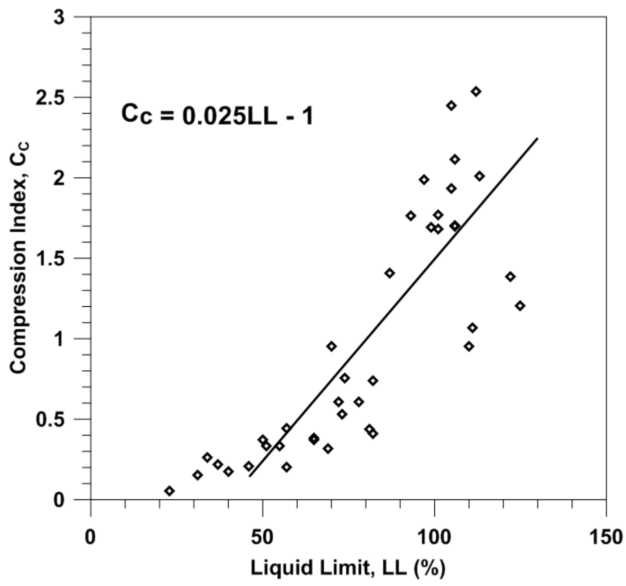

Figure 5 Relationship between C_c and Liquid Limit of Tokai Clay

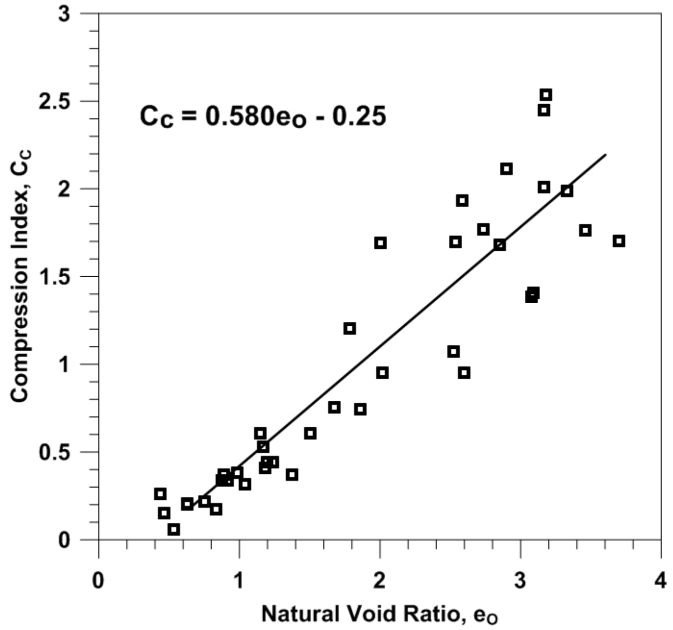

Figure 6 Relationship between C_c and Natural Void Ratio of Tokai Clay

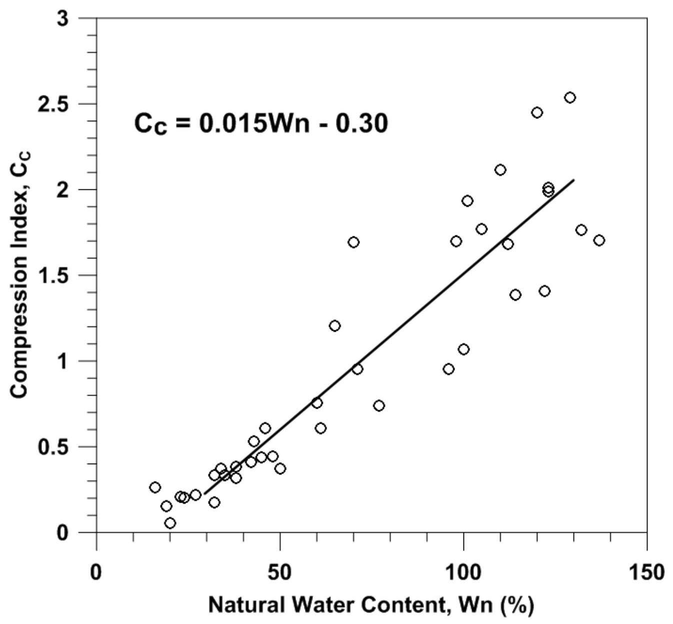

Figure 7 Relationship between C_c and Natural Water Content, W_n of Tokai Clay

Therefore, undrained shear strength is essential for the analysis of embankment stability (total stress). The undrained shear strength which characterised the strength of soft clay in undrained state can be measured using various laboratory and in-situ testing. However, due to the sensitivity of soft clay and disturbance introduced during sampling process, in-situ testing is much preferred particularly in Malaysia due to the process of sample collection, equipment, skill, etc. Thus, this paper will focus on the undrained shear strength obtained from field vane shear tests and piezocones. Figure 9 shows that the undrained shear strength of Tokai Clay increases almost linearly with depth and sensitivity obtained from field vane shear tests is about 2.4 to 5.2.

The commonly used correlation factors adopted in obtain undrained shear strength of soft clay from piezocone data are listed in Eq. (4), (5) and (6).

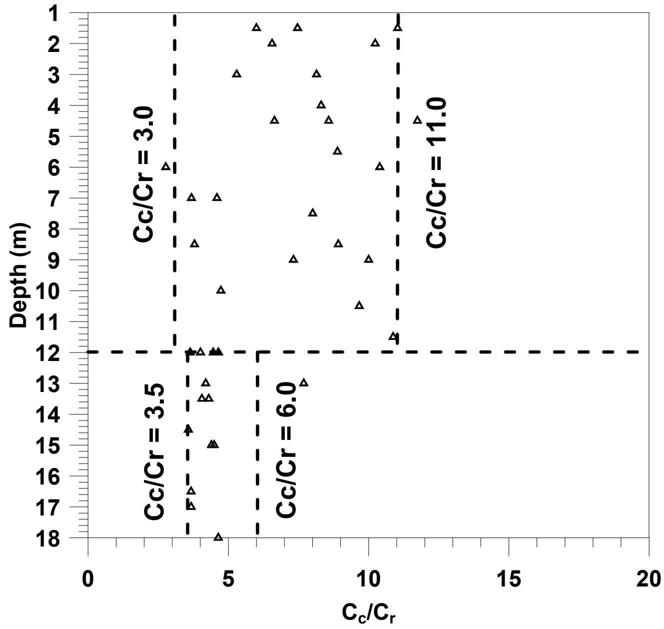

Figure 8 Ratio C_c and C_r of Tokai Clay

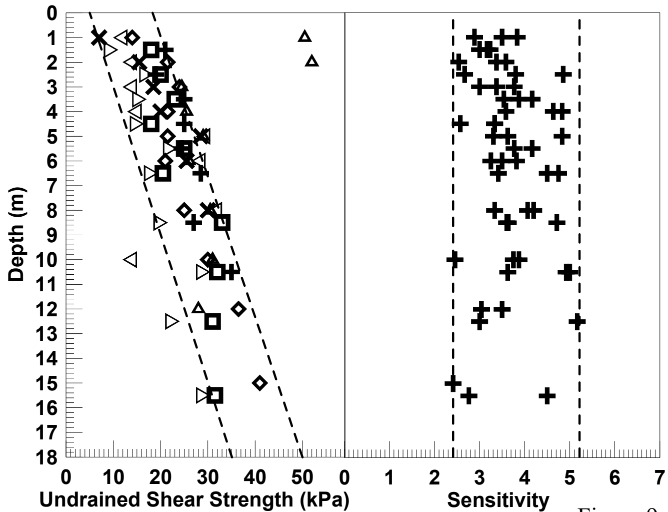

Figure 9 Undrained Shear Strength and Sensitivity of Tokai Clay

Thus, the correlation factors of N_k, N_{kt} and N_{ke} are being evaluated in this section. by comparing the undrained shear strength (s_u) obtained from the field vane shear test results with s_u measured from the piezocone.

$$s_u = \frac{q_c - \sigma_{vo}}{N_k} \tag{4}$$

$$s_u = \frac{q_t - \sigma_{vo}}{N_{kt}} \tag{5}$$

$$s_u = \frac{q_t - u_2}{N_{ke}} \tag{6}$$

The correlation factors obtained from the piezocone results are presented in Figures 10 to 12. The undrained shear strength values ($s_{u(fv)}$) used in the correlations were obtained from the field vane shear tests without any correction for plasticity index. The correlation factors for different type of empirical approaches are summarised in Table 1. The most frequent used empirical approach to estimate undrained shear strength is the corrected total cone resistance (q_t). Therefore, as shown in the Table 1, the Authors suggest to use average value of N_{kt} = 15 to estimate the undrained shear strength for Tokai Clay. This also coincides with the values recommended by Gue & Tan (2000) and Tan et al. (2004). Figures 10 to 12 illustrate the correlation factors interpreted from Piezocone results and undrained shear strength ($s_{u(fv)}$) from field vane shear tests.

Table 1 Correlation Factors for Tokai Clay

Correlation Factor	Values	Mean Value
N_{kt}	10 to 20	15.0
N_k	5 to 14	9.5
N_{ke}	4 to 12	8.0

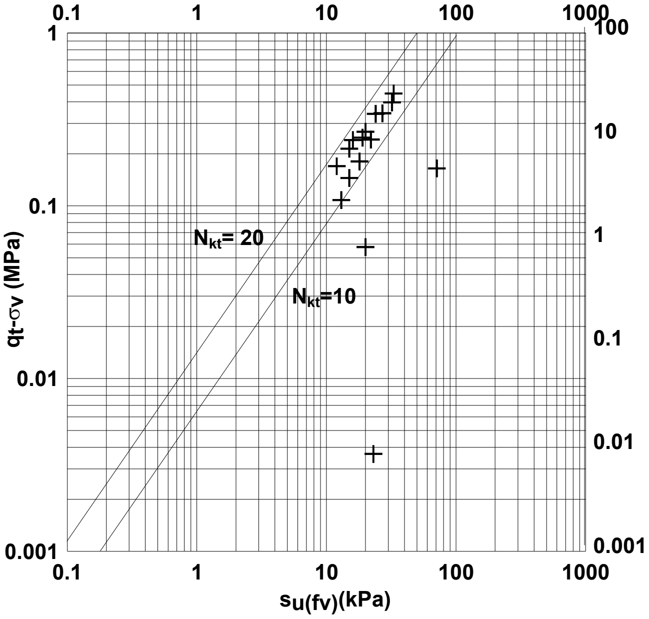

Figure 10 Corrected Total Cone Resistance against Uncorrected Field Vane Shear Strength

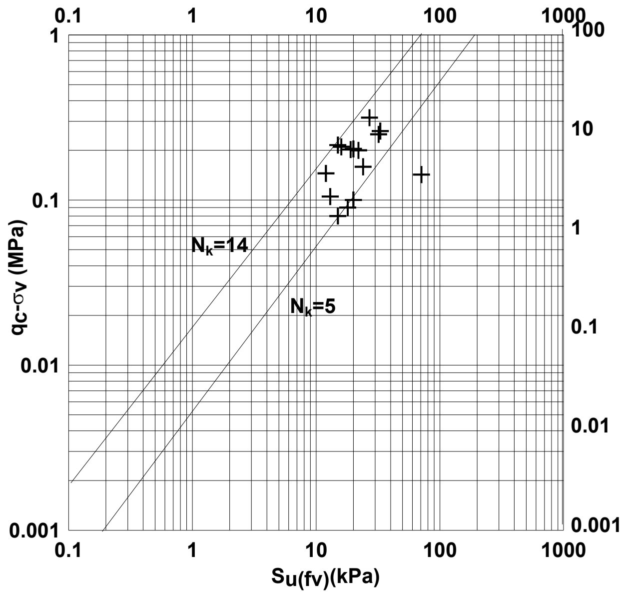

Figure 11 Corrected Total Cone Resistance against Uncorrected Field Vane Shear Strength

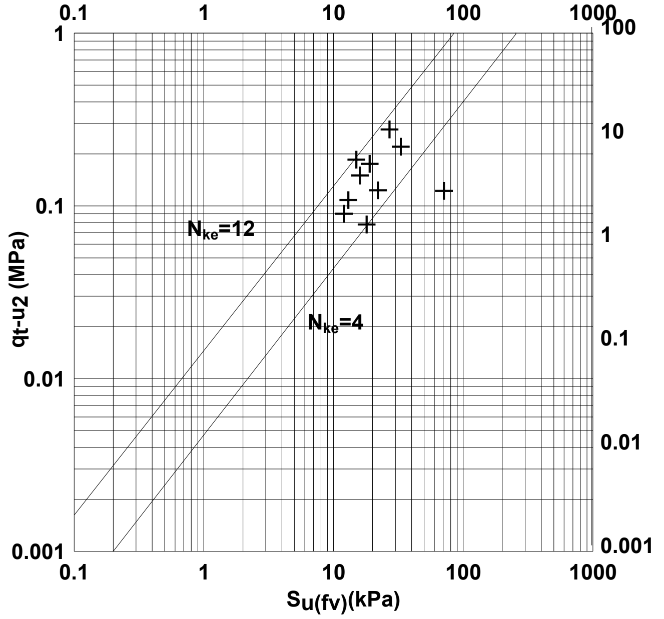

Figure 12 Effective Cone Resistance against Uncorrected Field Vane Shear Strength

5. CONCLUSION

The RR and CR of Tokai Clay range from 0.02 to 0.06 and 0.3 to 0.6 respectively. It can be observed that OCR decreases with increasing depth. Ratio of C_c/C_r of Tokai Clay is in the range of 3.0 to 11.0. Correlations of compressibility index of Tokai Clay have been presented in the paper. The obtained correlations show that C_c can be correlated well with Liquid Limit, natural void ratio and natural water content. The correlations obtained are close to the correlations obtained by Tan (2004) for Klang Clay.

The undrained shear strength of Tokai Clay increases almost linearly with depth. Empirical correlation factors used to correlate the undrained shear strength of Tokai Clay with piezocone data can be summarized as below:

Correlation Factor	Values	Mean Value
N_{kt}	10 to 20	15.0
N_k	5 to 14	9.5
N_{ke}	4 to 12	8.0

6. REFERENCES

Gue, S. S. and Tan, Y. C. (2000) "Planning of Subsurface Investigation and Interpretation of Test Results for Geotechnical Design". IEM Seminar on Geotechnical Enginnering, Penang.

Hussein, A. N. and Abdullah, K. (1998) "Some Piezocone Correlations for Soft Soil Deposits in Peninsular Malaysia ". Thirteenth Southeast Asian Geotechnical Conference, Taipei, Taiwan.

Khairul, N. Y., Lee, C. L., Phuai, P. G. and Saiful, A. A. T. (2006) " The correlations Between Chemical and Index Properties for Soft Clay of Peninsular Malaysia". Technology and Innovation for Sustainable Development Conference (TISD2006), Faculty of Engineering, Khon Kaen University, Thailand.

Michael, C. and Stephen, P. Bentley. (1991) "Correlations of Soil Properties". Pentech Press Limited, Graham Lodge, Graham Road, London NW4 3DG.

Tan, Y. C., Gue, S. S., Ng, H. B., Lee, P.T. (2003) "Some Geotechnical Properties of Klang Clay" 12th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering, Singapore.

Tan, Y. C., Gue, S. S., Ng, H. B., Lee, P. T. (2004) "Some Geotechnical Properties of Klang Clay", Malaysian Geotechnical Conference, Institute Engineers Malaysia.

Tan, Y. C., Lee, P. T., Koo, K. S. (2013) "Instrumented Trial Embankment on Soft Ground at Tokai State of Kedah, Malaysia". Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris.